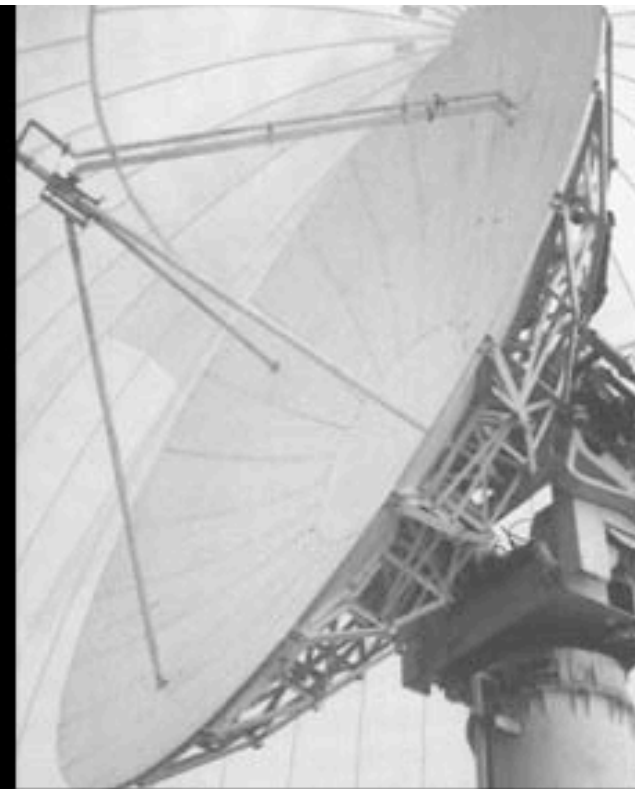


# Implementation of a Dish Radar Bias Model for Conjunction Assessment Simulation



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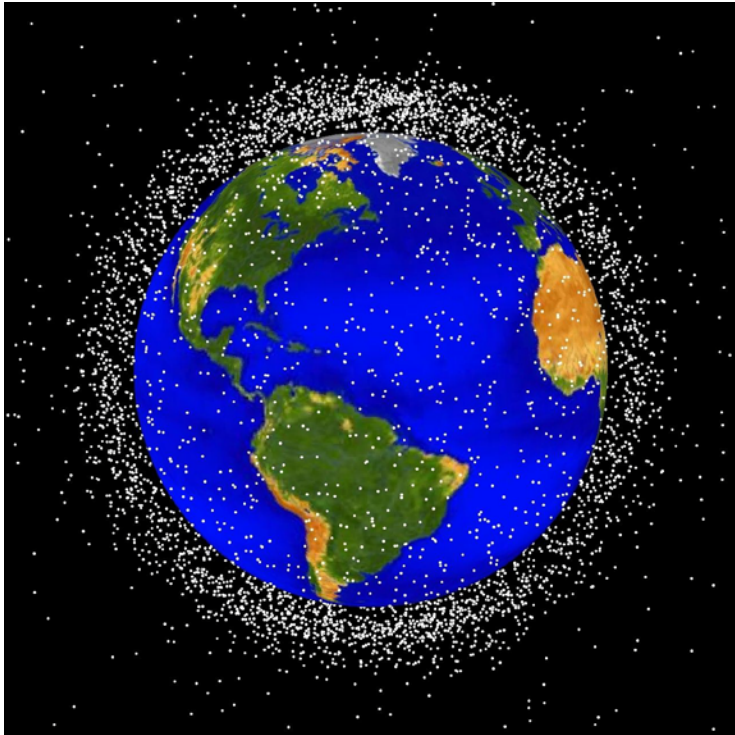


# Agenda

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2. Problem Definition
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4. Background
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  - Regression Analysis
6. Results
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8. Future Work
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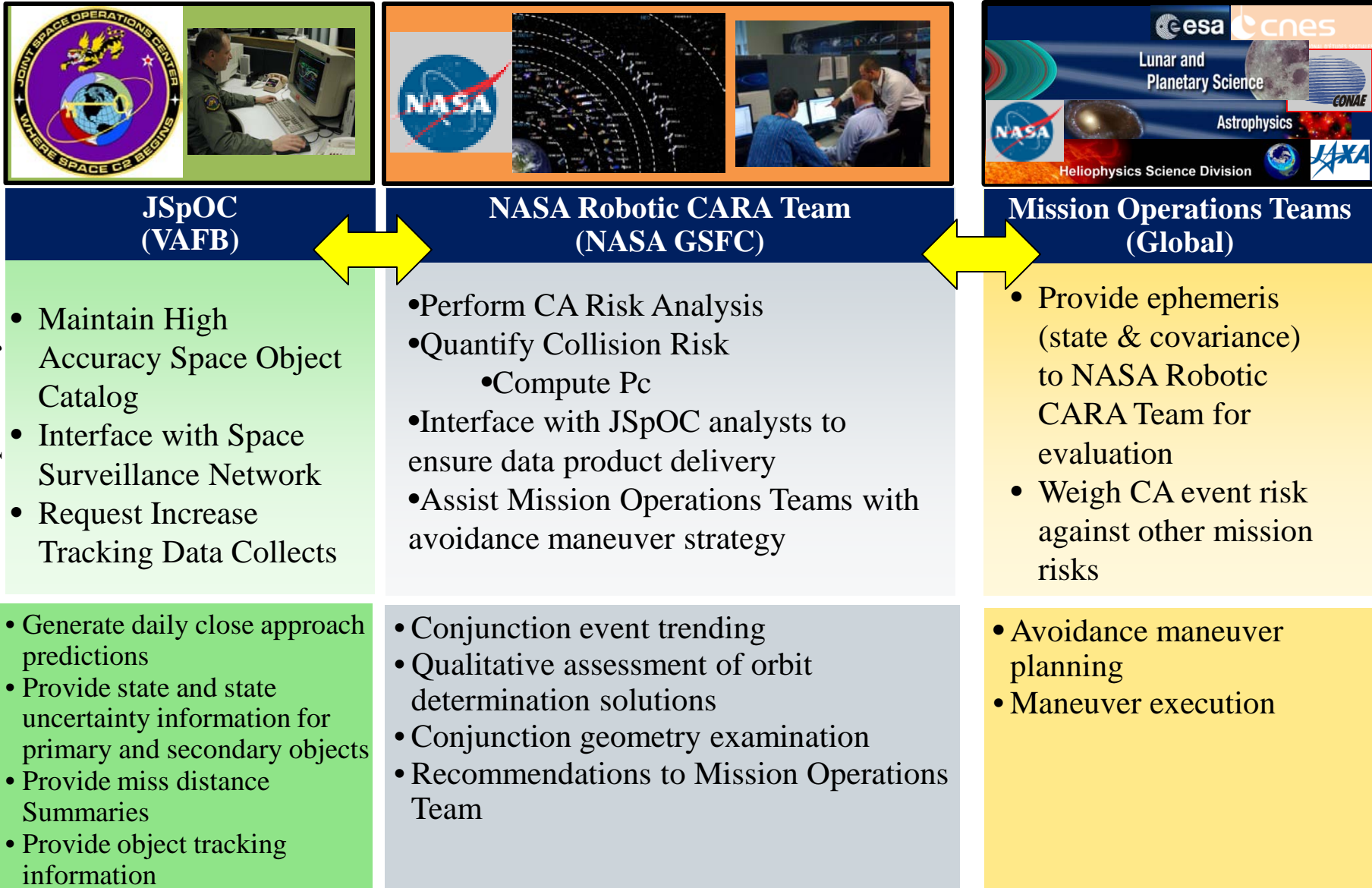
# Introduction



- Orbital debris poses threat to long term sustainability of space operations.
- Orbital debris mitigation efforts are in place
  - U.S. Space Policy
  - NASA policy
    - CARA



# NASA CARA Process



# Problem Definition

**A simulation that accounts for all the data items affecting the trajectory as the TCA nears is needed to improve event characterization**





# CA TCA Characterization Simulation

## **Modules:**

Tracking simulation

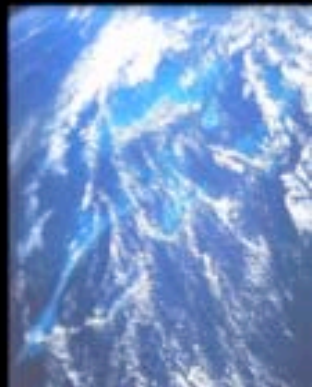
Observation noise

Sensor detectability

Orbit determination

Pc calculation

Monte Carlo framework



# Research Objective

To describe the implementation of the model used for the calibration of equipment-induced systematic biases found in dish radars.



# Background: SSN

<b>Dish Radars in the Space Surveillance Network (SSN) Table 1</b>	
<b>Sensor name</b>	<b>Year fielded</b>
Haystack Radar	1963
Haystack Auxiliary Radar	1993
Millstone Hill Radar	1957
Advanced Research Projects Agency (ARPA) Lincoln C-Band Observables Radar (ALCOR)	1970
ARPA Long Range Tracking and Instrumentation Radar (ALTAIR)	1970
Target Resolution and Discrimination Experiment (TRADEX)	1963
Millimeter Wave (MMW) Radar	1983
Globus II	1999
Ascension radar	1971



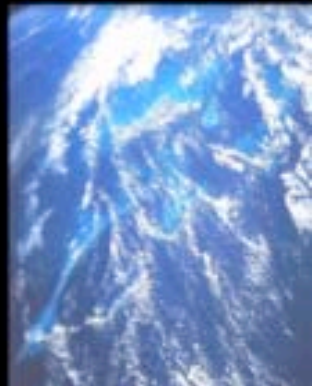
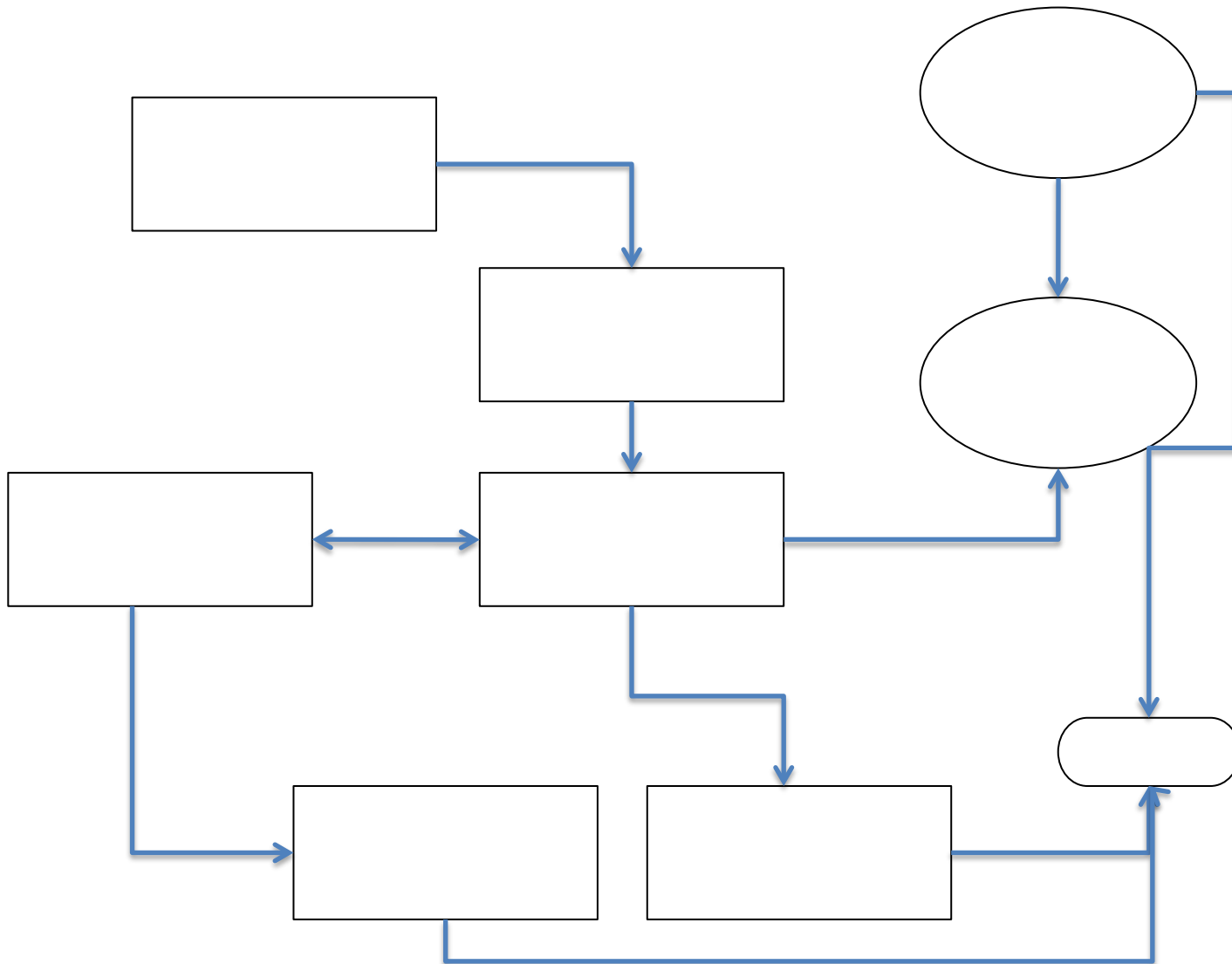


# Background (cont'd)

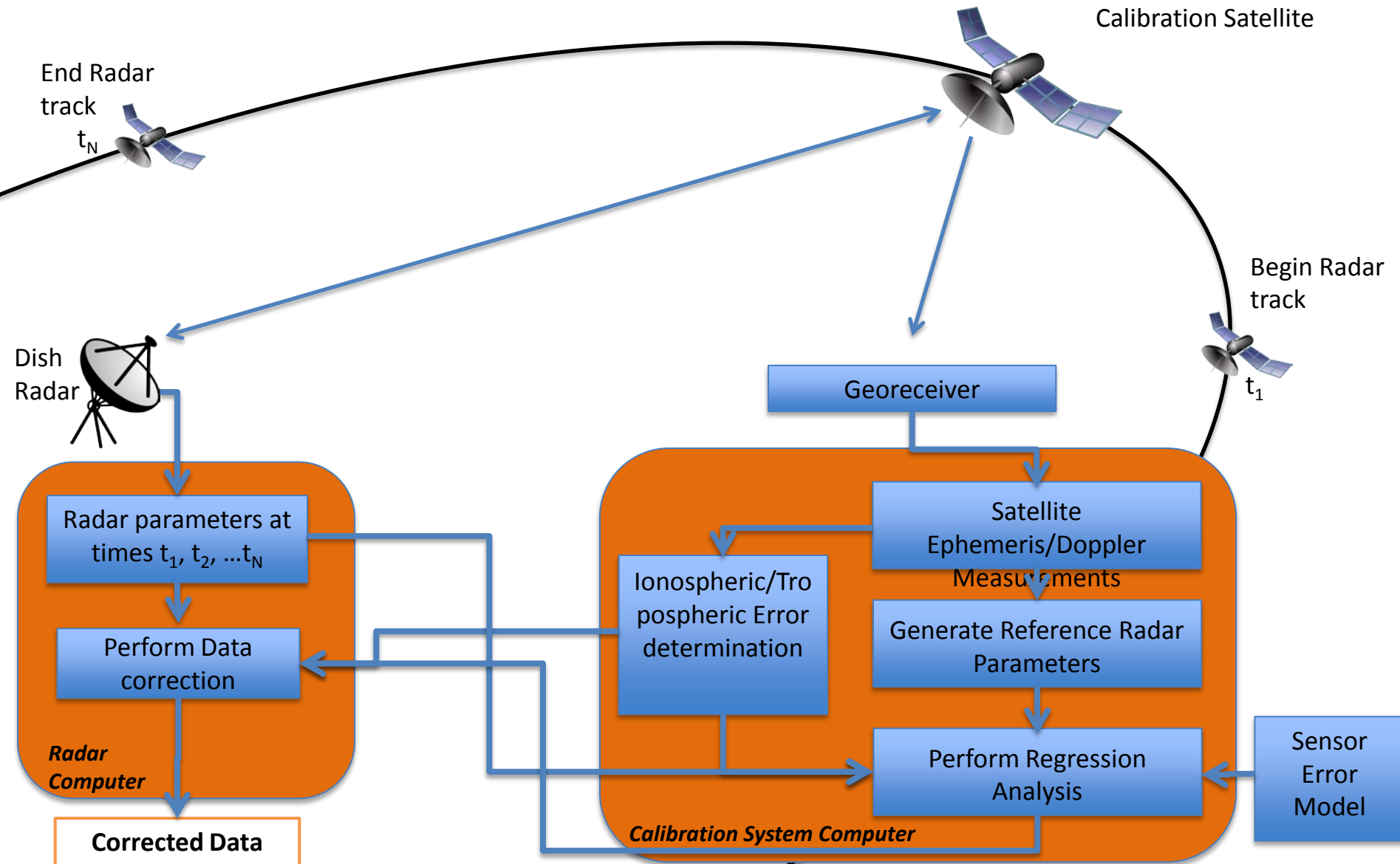
- In 1979, the MITRE Corporation performed an investigation on satellite-referenced calibration techniques.
- Derived an analytical model of the equipment-induced systematic biases in a generic tracking dish radar.



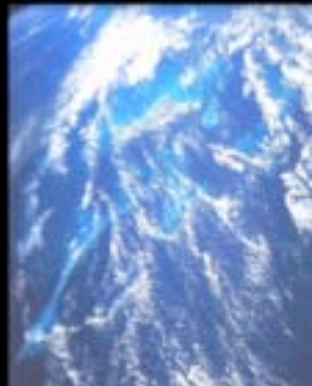
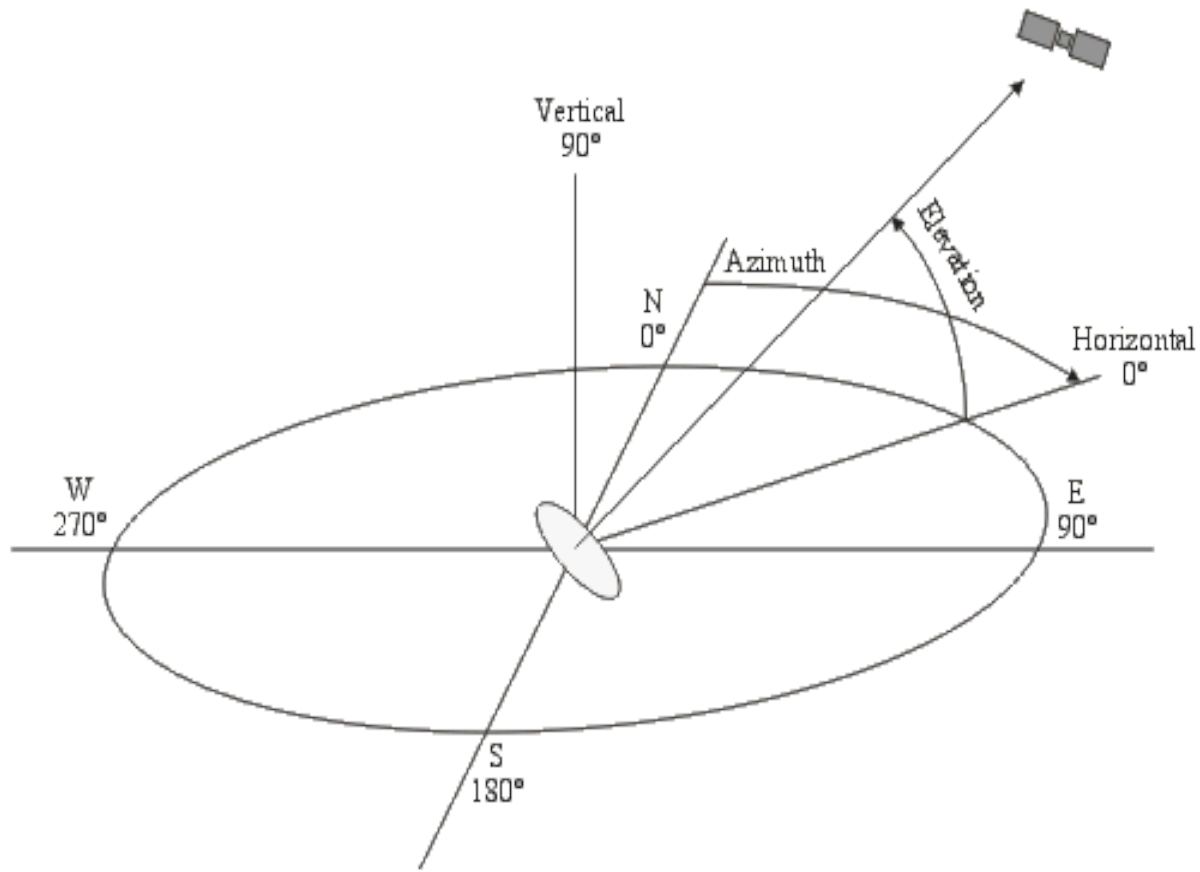
# Methodology



# Sensor Calibration



# Error Model



# Range Bias Correction, $\Delta R$

$$\Delta R = C_1 + C_3(R) + C_4(\dot{R}) + C_5(\ddot{R}) + C_7(\sin(Az)\cos(El)) + C_8(\cos(Az)\cos(El)) + C_9(\sin(El))$$

$C_1$  = Range bias [km]

$C_3$  = Range bias proportional to range [km/km]

$C_4$  = Range timing error [km/(km/s)]

$C_5$  = Range acceleration error [km/(km/s<sup>2</sup>)]

$C_7$  = Site position error (east) [km]

$C_8$  = Site position error (north) [km]

$C_9$  = Site position error (up) [km]



# Azimuth Bias Correction, $\Delta Az$

$$\Delta Az = \left[ \left( \frac{C_7}{DTRA} \right) \left( \frac{\cos(Az)}{(R)\cos(El)} \right) \right] + \left[ \left( \frac{C_8}{DTRA} \right) \left( \frac{-\sin(Az)}{(R)\cos(El)} \right) \right] + C_{10} + C_{11}(\ddot{Az}) +$$

$$C_{12}((P)\tan(El)) + C_{13}\left(\frac{P}{\cos(El)}\right) + C_{14}((\tan(El))(\sin(Az))) +$$

$$C_{15}((- \tan(El))(\cos(Az))) + C_{16}(\dot{Az}) + C_{17}((P)(\sin(Az))) +$$

$$C_{18}((P)(\cos(Az))) + C_{25}(CAHI) + C_{34}(CENC)$$

$C_7$  = Site position error (east) [km]

$C_8$  = Site position error (north) [km]

$C_{10}$  = Azimuth bias [deg]

$C_{11}$  = Azimuth acceleration error  
[deg/(deg/s<sup>2</sup>)]

$C_{12}$  = Non-orthogonality between azimuth  
and elevation axes [deg]

$C_{13}$  = Non-orthogonality between RF and  
elevation axes [deg]

$C_{14}$  = Azimuth axis tilt toward north [deg]

$C_{15}$  = Azimuth axis tilt toward east [deg]

$C_{16}$  = Azimuth timing error [deg/(deg/s)]

$C_{17}$  = Azimuth encoder error (#1) [deg]

$C_{18}$  = Azimuth encoder error (#2) [deg]

$C_{25}$  = Azimuth hysteresis error [deg]

$C_{34}$  = Azimuth square wave error [deg]





# Elevation Bias Correction, $\Delta El$

$$\Delta El = C_{19} - C_7 \left( \frac{\sin(Az) \sin(El)}{R} \right) - C_8 \left( \frac{\cos(Az) \sin(El)}{R} \right) + C_9 \left( \frac{\cos(El)}{R} \right) +$$

$$C_{14} (\cos(Az)) + C_{15} (\sin(Az)) + C_{21} (\dot{El}) +$$

$$C_{20} \left( El + \cos(El) + \sin(El) + \sqrt{\cos(El)} \right) + C_{27} ((S)(\dot{El}))$$

$C_{19}$  = Elevation bias [deg]

$C_7$  = Site position error (east) [km]

$C_8$  = Site position error (north) [km]

$C_9$  = Site position error (up) [km]

$C_{14}$  = Azimuth axis tilt toward north [deg]

$C_{15}$  = Azimuth axis tilt toward east [deg]

$C_{21}$  = Elevation timing error [deg/(deg/s<sup>2</sup>)]

$C_{20}$  = Elevation acceleration error  
[deg/(deg/s<sup>2</sup>)]

$C_{27}$  = Elevation hysteresis error [deg]



# Regression Analysis

Akaike Information Criterion (AIC):

$$AIC = (N) \ln \left( \frac{SS_{res}}{N} \right) + 2(K)$$

**N** = Number of data points

**SS<sub>res</sub>** = Sum-of-squares residual

**K** = Number of fitted coefficients plus one

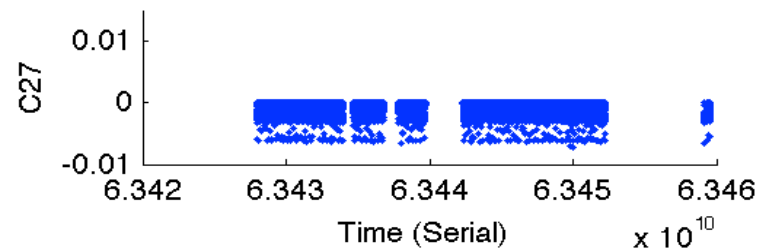
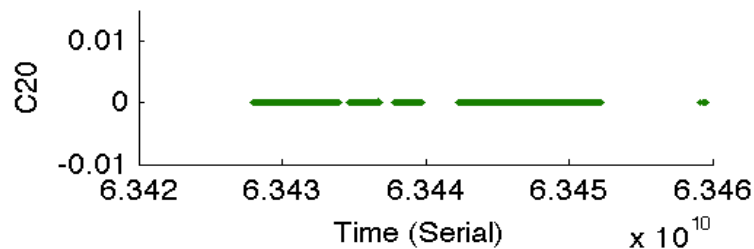
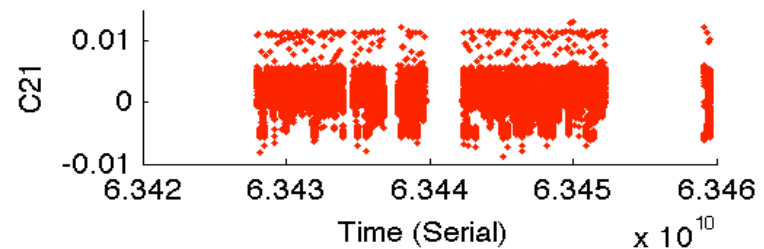
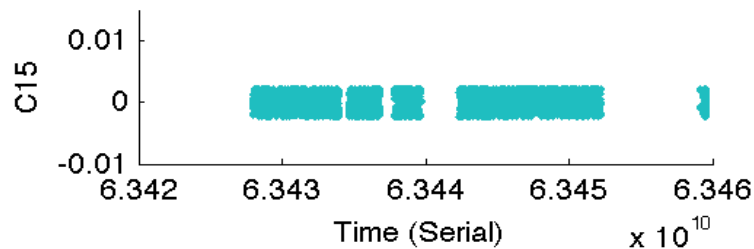
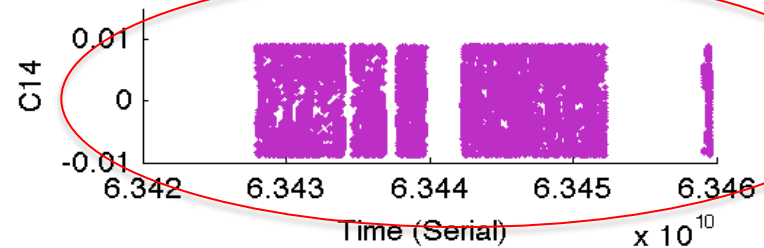
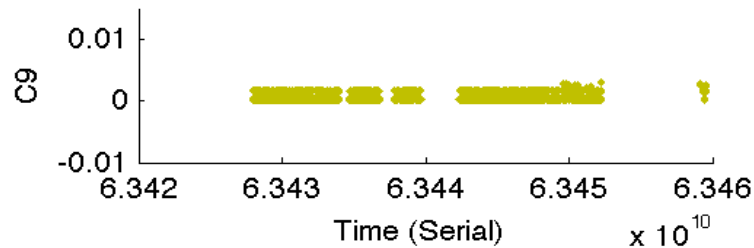
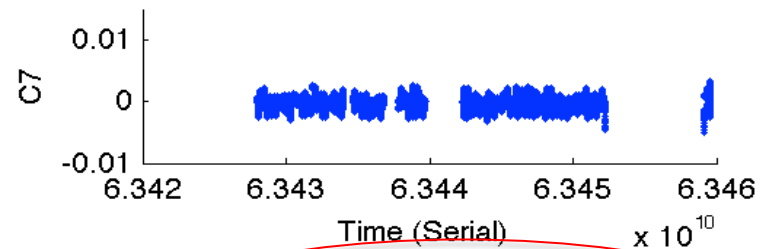
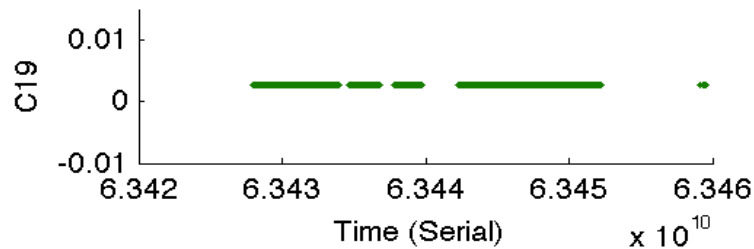


# Results

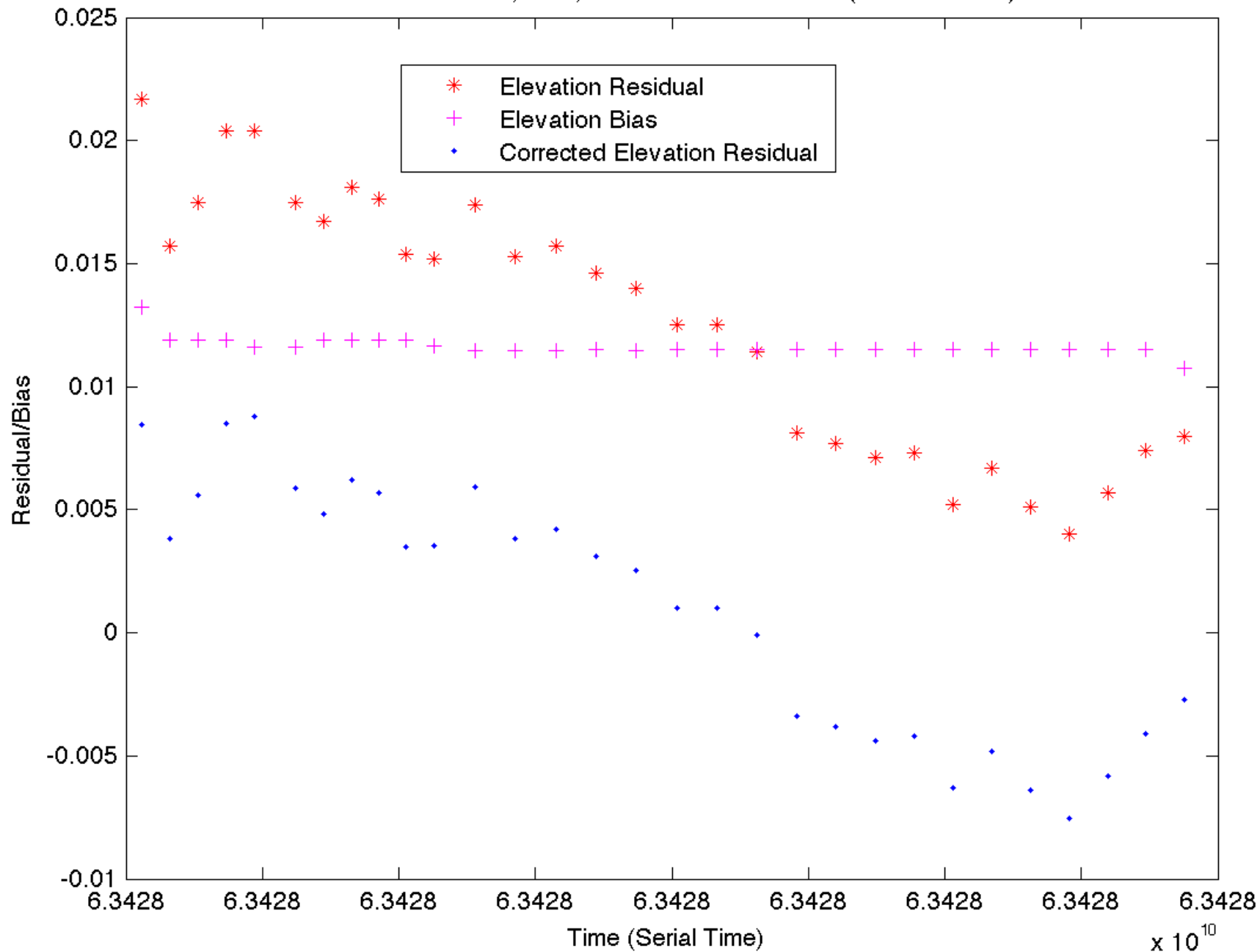
- ALTAIR L-band Calibration results will be discussed
  - Contained the largest amount of observations
- Original range, azimuth, and elevation residuals, biases, and corrected residuals were plotted against serial time.



# Elevation Bias Coefficients vs. Time

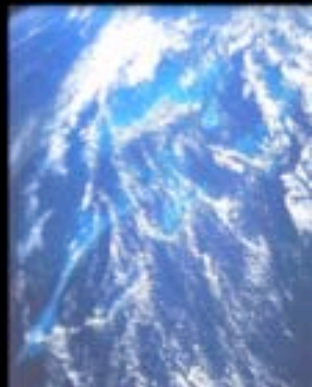


Elevation Residual, Bias, and Correction vs Time (For One Pass)



# Summary

- Analytical error model was implemented and regression analysis performed
  - Best-fit model of systematic biases was determined
- Best-fit model was used to remove systematic biases
- Validity of best-fit model and regression analysis was implied
- Model is fit for observation noise module





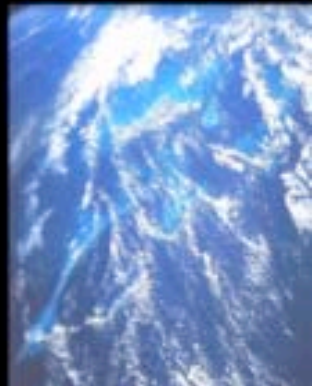
# Future Work

- Similar sensor calibration technique to be used for phased-array radars and optical sensor systems
- Implement ionospheric and tropospheric error model(s)
- Include all models in observation noise module



# Acknowledgements

- Lauri Newman
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# Any Questions?

